A High-Accuracy Measurement Of The Spin-Dependent Neutron Scattering Length Of The Deuteron

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Abstract. We give a brief report on the status of an experiment that has the goal to improve significantly the accuracy of the doublet neutron-deuteron scattering length a_2. This poorly known value is crucial for a better understanding of few-nucleon systems, in particular as an input for novel effective field theories of nuclear interactions. The value of a_2 can be obtained from a linear combination of the spin-independent nd scattering length $a_{c,d}$ and the spin-dependent one, $a_{i,d}$. The latter one is limiting the total accuracy and shall be determined at PSI in the present project with a relative accuracy of 10^{-3} using the method of pseudomagnetic precession of polarised neutrons passing through a polarised target.

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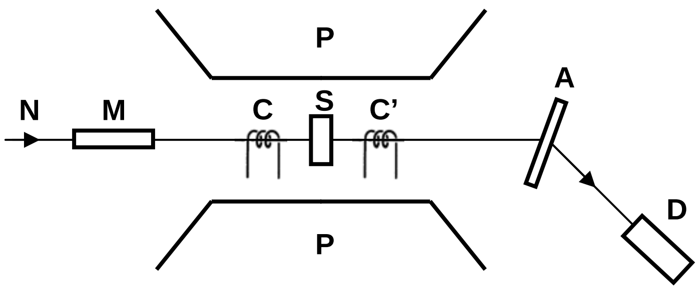
INTRODUCTION

In the past few years, effective field theories have been developed to describe nuclear forces at low energy [1]. In chiral perturbation theory, scattering amplitudes and other observables in systems of pions and nucleons can be expressed as systematic expansions in powers of ratios of small momenta and low-energy input parameters like the pion mass over the breakdown scale of the theory. Calculations are model-independent, providing, for the first time with estimate of the theoretical uncertainty, reliable predictions of many important low-energy quantities, in particular of processes in big-bang nucleosynthesis and stellar fusion. This requires input from experiments dedicated to determine a few so-called low-energy constants. Particularly suited to fix nuclear three-body forces is the doublet nd scattering length a_2 [2], which presently is known only with 6 % accuracy. It is obtained from a linear combination of the coherent nd scattering length and the spin-dependent, incoherent one, $a_{i,d}$. The former one is already accurately known and was further improved by a recent interferometric measurement at NIST [3]. The spin-dependent part will be measured by using the phenomenon of pseudomagnetic precession of the neutron spin in a nuclear polarised target [4,5], which is as a consequence of the spin-dependent neutron index of refraction. The pseudomagnetic precession angle is proportional to $a_{i,d}$ and will be measured using Ramsey's technique of separated oscillating fields [6].

EXPERIMENTAL SETUP AND RESULTS

The Ramsey apparatus (scheme see Figure 1), which will be employed to measure the angle of pseudomagnetic precession, has been set up and tested at the cold neutron beam FUNSPIN at SINQ at PSI. From the white polarised cold neutron beam (N) a monochromating supermirror (M) selects neutrons with a wavelength of $\lambda \sim 5$ Å with a bandwidth of $\Delta \lambda / \lambda \sim 8\%$ (FWHM). Two high frequency coils (C and C') located between the pole pieces of an electro magnet, that is stabilised with the help of NMR probes to $\Delta B/B = \pm 2\times10^{-7}$, are operated at about 72.4 MHz, corresponding to the neutron resonance frequency at 2.5 T. These coils flip the spin of the neutrons by $\pi/2$. A control loop stabilises their relative phase to ±0.05° and their amplitude to ±0.25%. The polarisation analysis is performed with a supermirror polariser (A). The so-called Ramsey resonance signal is then obtained by measuring the neutron count rate in the detector (D) as a function of the frequency of the flippers C and C'. The performance of the Ramsey apparatus is described elsewhere [7].



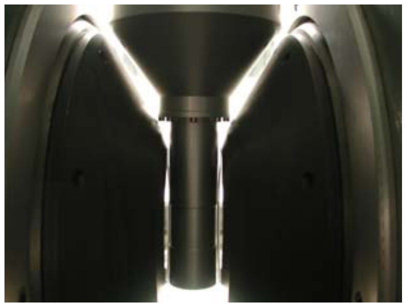


FIGURE 1. Left: Scheme of the Ramsey apparatus: N, white polarised neutron beam; M, monochromating supermirror; C, C', $\pi/2$-flipper rf coils; S, polarised sample; A, supermirror polarisation analyser; D, ^{3}He neutron counter; P, magnet pole pieces. Right: Vacuum nose of the dilution refrigerator of the frozen spin polarised target positioned between the pole pieces of the magnet.

A frozen spin polarised target (see Figure 1: Right) specially adapted for the use on a cold neutron beam has been constructed. The ^{3}He-^{4}He dilution refrigerator has a heat exchanger between ^{3}He-^{4}He mixing chamber and the target cell filled with ^{4}He, in order to avoid that the beam has to pass through the strongly absorbing ^{3}He. After the polarisation process is finished the polarising microwaves are turned off and the sample is cooled to a temperature of below 100 mK, sufficient to freeze the polarisation of the sample material.

During a first experimental run a polarised deuterated plastic target was used, and the phase-shift of the Ramsey signal was observed, caused by the pseudomagnetic neutron precession in the polarised nuclear target. The measured phase-shift was accompanied by damping of the Ramsey signal (see Figure 2) which we believe is due to inhomogeneities in the sample – either because of inhomogeneities of the density, or the nuclear polarisation or both.

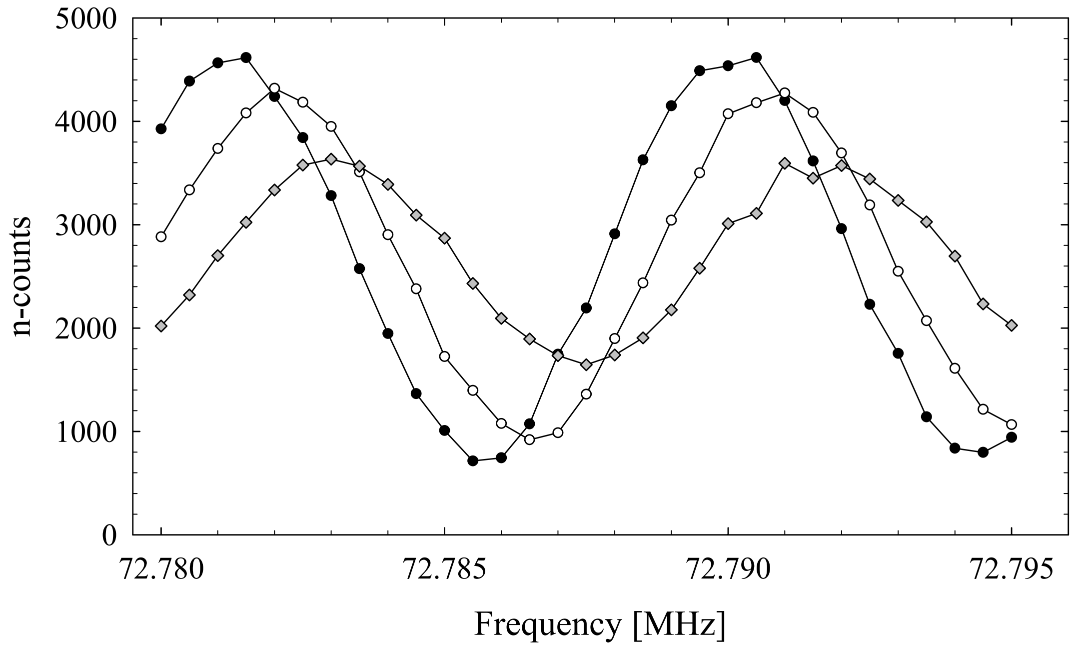


Figure 2 Measurements of neutron intensities in the centre of the Ramsey signal, performed with a polarised plastic target. With increasing nuclear polarisation the pseudomagnetic phase shift is increasing but the signal amplitude gets more and more damped.

For this reason several different target materials are now being investigated in a ^{4}He cryostat at 1 K that allows a quick change of samples. From the experience made so far with a large range of samples (plastics and frozen alcohols with various concentrations of deuterons and paramagnetic centres), it seems nonetheless, that a deuterated plastic target can be chosen for the actual measurement planned for 2006. It should, however, be prepared in a slightly modified process.

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